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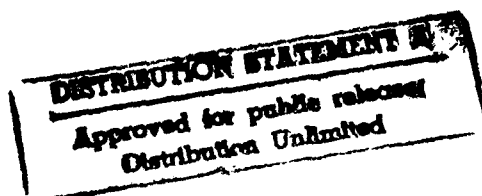
NAWCAD DIRECT DRIVE
SYSTEM STATUS/
RESEARCH & DEVELOPMENT

1994

MR. KURT SEBACHER
MR. SAM FRAZIER

NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION
PATUXENT RIVER, MD 20670-5304
(301) 826-3873

This presentation will discuss the Naval Air Warfare Center Aircraft Division's direct drive system. The system status, present research, proposed research and development of a improved direct drive system will be discussed. This presentation is written by Kurt Sebacher and Sam Frazier, both from the Naval Air Warfare Center Aircraft Division (Patuxent River).



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Enclosure (5)

TO WHOM IT MAY CONCERN:

Here is a copy of Professional Papers written by various people here at the Naval Air Warfare Center Aircraft Division. It was requested that a copy of each of the professional papers be sent to DTIC for retention.

If you have any questions, please contact Dorothy Reppel, 326-1709 or (301) 826-1709.

P.S. All the enclosed papers have been cleared for public release.

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DIRECT-DRIVE (D-D)



OVERVIEW:

- BACKGROUND
- STATUS
- PRESENT R&D (FY93)
- PROPOSED R&D (FY94-96)
- SUMMARY

This presentation will discuss direct drive; background, status, present R&D, proposed R&D, and summary



DIRECT-DRIVE (D-D)



BACKGROUND:

- WHAT IS IT?
- ROLE IN E³ RDT&E
- HISTORICAL PERSPECTIVE
- DIRECT-DRIVE SPECIFICATIONS IN MIL-STD-461/462
- NAWCAD DEVELOPMENT GOALS

The background will discuss; what is direct drive?, the role in E3 RDT&E, the history of direct drive, direct drive specifications in MIL-STD-461/462, and the direct drive development goals of NAWCAD.



WHAT IS DIRECT-DRIVE (D-D)?



TEST METHOD TO DETERMINE, CHARACTERIZE, OR DEVELOP
SUBSYSTEM STRENGTH AS PART OF A SYSTEM LEVEL TEST

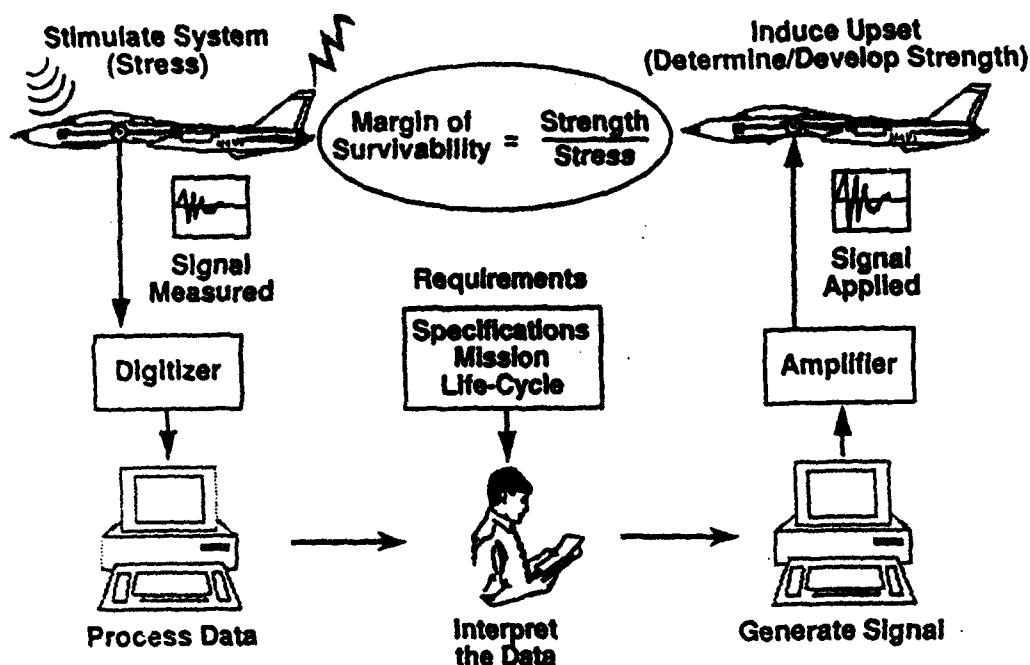
- USUALLY INDUCTIVE COUPLING
- CAN ALSO BE DIRECT INJECTION, RADIATED OR CAPACITIVELY COUPLED

D-D IS CRITICAL TO QUANTIFYING SURVIVABILITY OR
CHARACTERIZING VULNERABILITIES

Direct drive is used at NAWCAD as a test method to determine, characterize, and develop subsystem strength as part of a system level test. Though NAWCAD primarily uses direct drive in an inductively coupled manner, it can be radiated or capacitively coupled. NAWCAD believes direct drive is essential for quantifying the survivability/vulnerability of subsystems.



PROCESS



This drawing illustrates the direct drive process. The test object is stimulated in an EM environment. The stress resulting from this stimulation is measured on specific test points (bulk cables or individual wires). The data is interpreted and reviewed by the engineer. The signal is then reapplied to the specific test point at threat/threat plus margin levels. The drive level is increased until upset occurs or a predetermined margin level is reached. This level is the components strength. The margin of survivability is determined by dividing strength by stress.



D-D ROLE IN E³ RDT&E



APPLICABLE TO ALL EM SURVIVABILITY DISCIPLINES USING MARGINS

- MIL-STD-461/462
- LIGHTNING
- EMP
- EMR/EMV/EMI
- HPM
- UWB

CW, FM, AM, PULSED, BURST, ETC

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Direct drive testing can be used for all EM disciplines using margins such as; MIL-STD-461/462, lightning, EMP, EMR, HPM, and UWB. The test source can be; CW, FM, AM, Pulse, or Burst.



HISTORICAL PERSPECTIVE



INITIAL D-D R&D PERFORMED IN 1970's

- DAMPED SINUSOIDAL WAVEFORMS
- LARGE MARGINS REQUIRED TO BOUND MULTITUDE OF UNCERTAINTIES & POOR FIDELITY

PRESENT TECHNOLOGY ADEQUATE TO REASSESS FUNDAMENTALS OF NARROWBAND D-D TECHNOLOGY

- WIDEBAND D-D CAPABILITY
- POWERFUL SIGNAL PROCESSING TOOLS
- APPLY ALL DATA TO MARGIN/ISSUES

Direct drive research as initially performed in the 1970s. Damped sinusoidal waveforms were used which lead to the need for large margins to bound a multitude of uncertainties and poor fidelity. Recent advances in simulation technology has allowed researchers to reassess the fundamentals of narrowband direct drive technology. The emergence of the Arbitrary Waveform Generator has allowed wideband direct drive to become a reality. Powerful signal processing tools have allowed the application of all data in the direct drive process.



D-D SPECIFICATIONS & REQUIREMENTS IN MIL-STD-461D/462



MIL-STD-461D/462

- CS114 - REPLACES CURRENT TESTS (CS02 & RS02)
 - REPLACES PART OF RADIATED SUSCEPTIBILITY TEST (RS03)
- CS115 - REPLACES CHATTERING RELAY TEST (RS06)
- CS116 - REPLACES SPIKE REQUIREMENTS (CS06 & RS02)
 - DELETE CS10
 - CS11 NO LONGER FOR EMP ONLY (INCLUDES LIGHTNING AND OTHER TRANSIENT PHENOMENA)

Direct drive testing has increased in the new MIL-STD-461D/462 specification. Test techniques CS114, CS115, and CS116 replace or augment radiated tests like RS02, RS03, RS06. The use of direct drive is emerging since the test environment is easier to control and threat plus margin levels are more readily attainable.



NAWC-AD DIRECT-DRIVE DEVELOPMENT GOALS



DOD CENTER OF EXCELLENCE FOR DIRECT-DRIVE TECHNOLOGY

STRESS

COMBINE ALL AVAILABLE SYSTEM RESPONSE DATA TO DEVELOP
BOUNDING STRESS ENVELOPE

- HIGH LEVEL PULSE, LOW-LEVEL, CONTINUOUS WAVE,
DESIGN/ANALYSIS OR THEORETICAL DATA

STRENGTH

RECREATE WIDEBAND ENVELOPE IN SINGLE EVENTS AND AMPLIFY TO
LEVELS WHICH DEMONSTRATE SURVIVABILITY OR CHARACTERIZE
STRENGTH

IMPROVEMENTS MUST NOT INCREASE USER TEST
TIME OR COST

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NAWCAD's direct drive development goals include becoming part of the DoD center of excellence for direct drive testing and technology. The objectives are divided into two parts, stress and strength. For stress, we are interested in combining all available response data into one bounded stress waveform. This includes different orientations, configurations, and stimulation sources. For strength determination we are intent on being able to exactly recreate the wideband test envelope and amplify to above threat margins.



DIRECT-DRIVE (D-D)



STATUS

The status of the existing direct drive system is:



PRESENT D-D CAPABILITY



D-D CAPABILITY COMPRISES SEVERAL TECHNOLOGIES

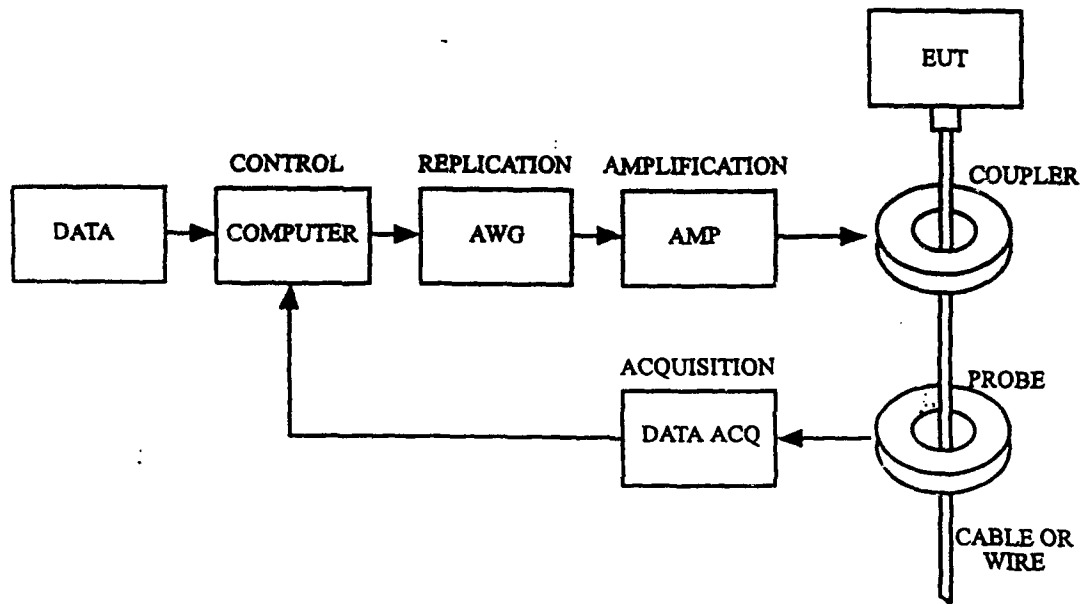
- CHARGE-LINE PULSERS -- MIL-STD-461D
- NARROWBAND RF (DAMPED SINE) -- MIL-STD-461C/461D
- DIRECT-INJECTION -- MIL-STD-1757 AND 1795
- WIDEBAND

MOST PRESENT R&D FOCUSES ON WIDEBAND SYNTHETIC WAVEFORM
DIRECT-DRIVE

Direct drive encompasses several technologies including; charge line pulsed, narrowband RF, direct skin injection, and wideband current injection. Most of the R&D focuses on wideband current injection direct drive.



DIRECT-DRIVE WAVEFORM PATH



This illustration shows the direct drive waveform path. The data is loaded on a computer which in turn loads the arbitrary waveform generator. The signal is amplified and inductively coupled onto the test point. A current probe is used to measure the applied signal which is recorded on the data acquisition system. The waveform is then stored on the computer. Though this process is easy in concept it has proven difficult in execution.



WIDEBAND D-D CAPABILITY



HARDWARE

- PULSE AMPLIFIERS - 10 & 11.25 kW (10 kHz - 100 MHz)
- CW AMPLIFIERS - 1 kW (10 kHz - 200 MHz)
- ARBITRARY WAVEFORM GENERATORS - 2 LECROY 9100, 1 ANALOGIC 2040
- 50 COUPLERS - VARIOUS MODELS & SIZES, WIND CORES IN-HOUSE FOR SPECIFIC TESTS -- 1 kHz - 1 GHz
- STANDARD INSTRUMENTATION -- UP TO 1 GHz
- PC CONTROL

SOFTWARE

- STANDARD SIGNAL PROCESSING TOOLS
- REAL-TIME NORMALIZATION

NAWCAD direct drive system encompasses two pulsed amplifiers (10, 11.25 kW) and one CW amplifier (1 kW). Two different arbitrary waveform generators are available for use (50 MHz and 200 MHz). Various size couplers with different core material and windings were built at NAWCAD with useable frequency ranges from 1 kHz - 1 GHz. Instrumentation up to 1 GHz to measure the waveform is available. Standard signal processing tools to combine and prepare the data are used. Special in-house normalization processes are used to increase the useable frequency range of the direct drive system.



WIDEBAND D-D CAPABILITY



EMP

- STRESS RESPONSE DATA REINJECTED AT THREAT PLUS MARGIN LEVELS
 - MARGIN LEVELS OF 10 dB FOR STRATEGIC AIRCRAFT
 - MARGIN LEVELS OF 32 dB FOR TACTICAL AIRCRAFT

LIGHTNING

- STRESS RESPONSE DATA REINJECTED AT THREAT PLUS MARGIN LEVELS
 - MARGIN LEVELS OF 6 dB

The direct drive system to date has primarily been used for EMP and lightning testing. Margins of up to 32 dB above threat are needed for EMP and 6 dB above threat for lightning.



DIRECT-DRIVE (D-D)



PRESENT RESEARCH AND DEVELOPMENT

The present R&D efforts will be discussed



STRESS ENVELOPE R&D



BOUNDED WORST-CASE WAVEFORM

- CONSTRUCTED FROM MULTIPLE SOURCES:
HIGH-LEVEL PULSE, LOW-LEVEL CW & ANALYSIS
- PROVIDES MAXIMUM STRESS WAVEFORM REGARDLESS OF TUAL
OR SIMULATED AIRCRAFT-THREAT SCENARIO
- REDUCES TEST UNCERTAINTIES

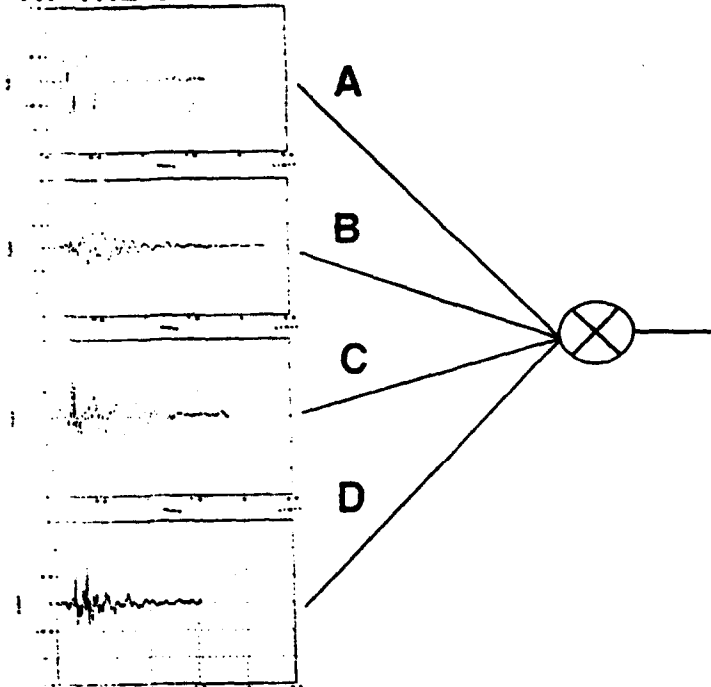
A goal for the direct drive system is the ability to develop a stress envelope that encompasses a multitude of sources, configurations and orientations. This will ensure the maximum stress waveform is applied against the aircraft, and reduces test uncertainties.



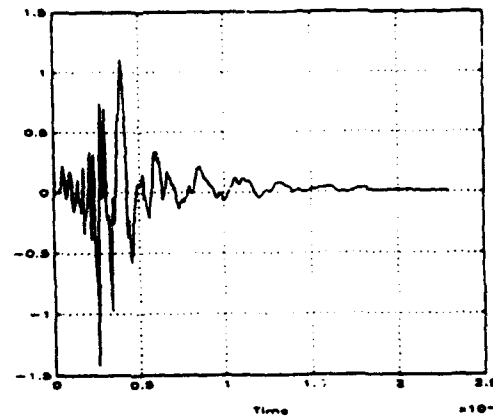
CONSTRUCTING AN ENVELOPE



VARIOUS WAVEFORM RESPONSES AT THE SAME TEST POINT



STRESS ENVELOPE



COMBINE A, B, C, & D

This drawing illustrates four various waveform responses on the same test point combined to develop one maximum stress waveform envelope. The combination is achieved using an AR or ARM subroutine.



NORMALIZATION R&D



INCREASES EFFECTIVE D-D SYSTEM BANDWIDTH AND MORE
CLOSELY REPLICATES ORIGINAL STRESS WAVEFORM

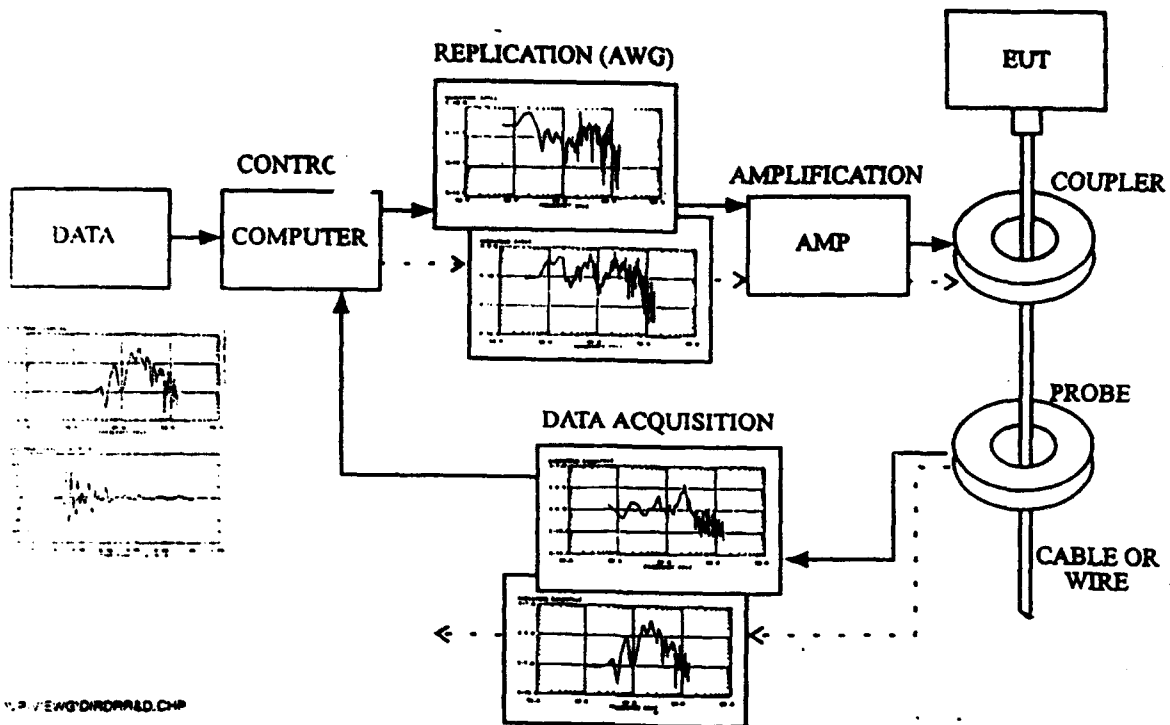
- COMPENSATES FOR SYSTEM NON-LINEARITIES AND COUPLER ROLL-OFFS
- COMPENSATES AND ESTIMATES TEST POINT LOAD IMPEDANCE

$$\text{NORMALIZED WAVEFORM} = \text{DESIRED WAVEFORM} \times \frac{\text{DESIRED WAVEFORM}}{\text{MEASURED WAVEFORM}}$$

A software process developed at the Naval Air Warfare Center Aircraft Division called Real Time Waveform Normalization has allowed the direct drive system to increase it's effective bandwidth and better replicate the original stress waveform. This process compensates for system non-linearities and coupler roll-offs. The test point load impedance is also estimated and used for compensation. During this process the output of the first direct drive attempt is used to adjust the original direct drive waveform for the effects mentioned above. Succeeding direct drive testing then uses the adjusted direct drive waveform. The adjustment process to the direct drive waveform is shown in the equation. All adjustment processing is performed in the frequency domain. When dividing measurements in the frequency domain, the domains of each measurement should be compatible in terms of number of data points and data point spacing. If they are not compatible an interpolation process can be used.



DIRECT-DRIVE WAVEFORM PATH



This illustration shows the path the waveform takes during the normalization process.



LOAD IMPEDANCE R&D



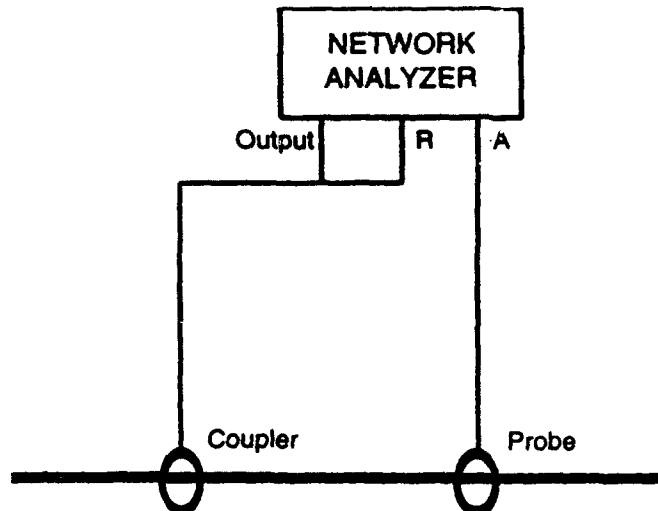
DETERMINE OPTIMUM METHOD FOR OBTAINING LOAD IMPEDANCE DATA

- INTEGRATE LOAD IMPEDANCE MEASUREMENT INTO TEST PROCESS
 - GATHER DURING TEST POINT SCREENING OR D-D
 - STORE AS INTEGRAL PART OF TEST DATA
- COMPARE LOAD IMPEDANCE EXTRACTED FROM REAL-TIME NORMALIZATION TO NETWORK ANALYZER MEASUREMENTS
- USE LOAD IMPEDANCE TO IMPROVE TEST-POINT & SYSTEM MODELING & ANALYSIS

Another way of normalizing the data is directly obtaining the load impedance of the test point. As mentioned above the real time normalization process will determine the test point load impedance while the direct drive test is being performed. A method of determining test point load impedance before the direct drive test is to take a network analyzer measurement.



LOAD IMPEDANCE



LOAD IMPEDANCE FOUND AS FUNCTION OF FREQUENCY

This illustration shows the setup for measuring test point load impedance as a function of frequency using a network analyzer.



DOD-STD-2169A D-D R&D



NO WIDEBAND DOD-STD-2169A D-D CAPABILITY EXISTS

- **SPONSORED PHILLIPS LAB DEVELOPMENT OF HIGH FREQUENCY NOISE GENERATED D-D SOURCE TO AUGMENT NAWC AD SYSTEM**
- **PRESENT SYSTEM & PHILLIPS SYSTEM TO BE COMBINED TO PROVIDE WIDEBAND ARBITRARY WAVEFORM CAPABILITY FROM 10KHZ TO 1GHZ**
- **NAVAL AIR SYSTEMS COMMAND WILL REVIEW FINAL D-D SYSTEM & PROCESS FOR ADEQUACY TO QUALIFY AIRCRAFT SYSTEMS TO DOD-STD-2169A THREAT**

NAWCAD is currently working with Phillips Lab and Kaman Sciences to develop a high frequency noise generated waveform generator. A prototype system has been developed.

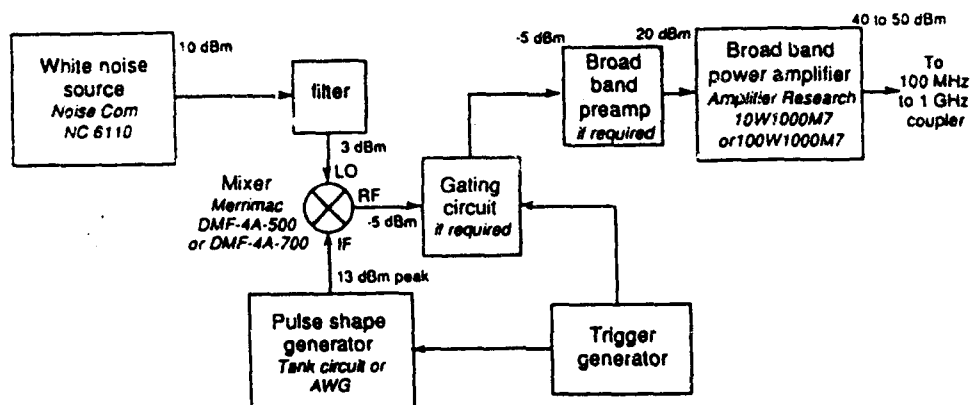


DOD-STD-2169A DIRECT-DRIVE



PROTOTYPE NOISE SOURCE DIRECT DRIVE SYSTEM

Below is a block diagram of a noise source waveform generator constructed by Kaman as a proof-of-principle demonstration. Prototype will be used for subsystem testing.



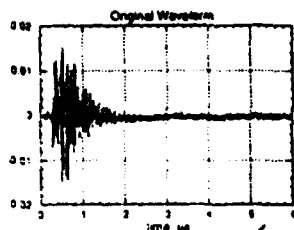
This diagram shows the setup for the high frequency noise source direct drive system. A white noise source is run through specific filters to allow desired frequencies to pass through. This filtered noise is then mixed with the output of an AWG which is used to shape the waveform. The resulting waveform is amplified and inductively coupled on the test cable.



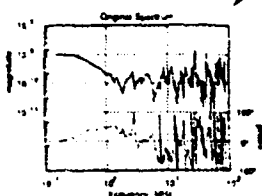
DOD-STD-2169A DIRECT-DRIVE



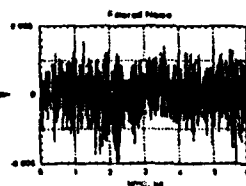
SYNTHETIC WAVEFORM CONSTRUCTION



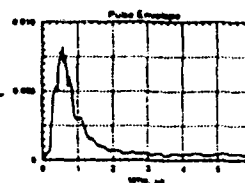
White noise contains all frequency components necessary to replicate any waveform. In this example the magnitude of the spectrum of the original waveform is used as a filter function while the waveform envelope is employed as a modulation function.



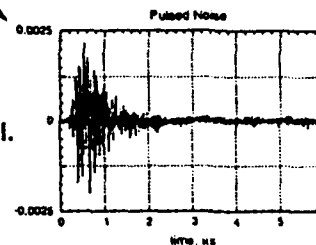
Shape of spectrum used as filter for white noise



Pulse envelope used to modulate filtered white noise



The resulting waveform closely resembles the original.



This diagram shows how the synthetic waveform is constructed. The noise source is filtered and then the drive waveform is shaped by the pulse envelope from the AWG. Though the waveforms produced will be random, since we are using a noise source, experiments have shown that variations are acceptable.



DIRECT-DRIVE (D-D) R&D



PROPOSED R&D (FY94-96)

- PULSE FORMING NETWORKS
- NON-TRANSIENT E³ ENVIRONMENTS
- COUPLING METHODS
 - INDUCTIVE - RADIATED - DIRECT - DISTRIBUTED - DIFFERENTIAL
- VOLTAGE RESPONSE CHARACTERISTICS
- CORRELATION OF FREE-FIELD & D-D UPSETS
- MULTIPOINT COUPLING EFFECTS ON SYSTEM RESPONSE
- WIRE VS. BULK COUPLING ISSUES

The proposed R&D for the next couple of years include; pulse forming networks, different coupling methods, investigating correlation problems and including more non-transient environments into direct drive testing.



D-D R&D SUMMARY



- D-D CRITICAL TO QUANTIFICATION OF AIRCRAFT ELECTROMAGNETIC SURVIVABILITY
- TECHNOLOGY AVAILABLE FOR SIGNIFICANT IMPROVEMENTS
- NAWC AD ENGAGED IN SEVERAL D-D R&D PROJECTS
- MAJOR ISSUES STILL REQUIRE INVESTIGATION AND RESOLUTION

In summary direct drive testing is critical to quantifying an aircraft's electromagnetic survivability. Technology advances have allowed direct drive to become broadband. NAWCAD has begun R&D to improve direct drive testing and technology. However, major issues still need to be investigated.